



EVA

Development and Verification Testing at NASA's Neutral Buoyancy Laboratory

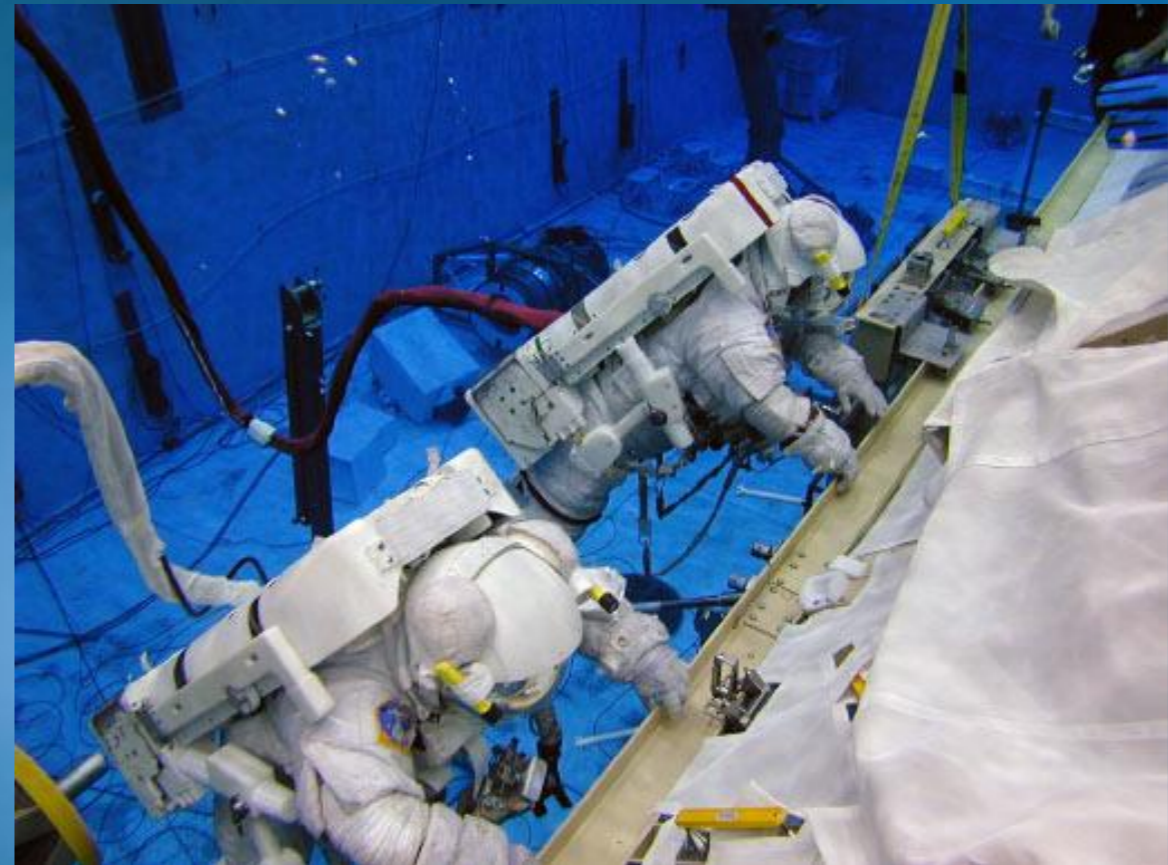
Juniper Jairala



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Purpose

- Increase the larger community's awareness about the Neutral Buoyancy Laboratory (NBL)
- Share why & how EVA development & verification testing is conducted at the NBL
- Share ideas on use of the NBL for future NASA & commercial human spaceflight programs



Agenda

Background

Test Philosophy

Facility & Test Setup

Test Planning (Roles & Responsibilities)

Test Hardware & Mockups

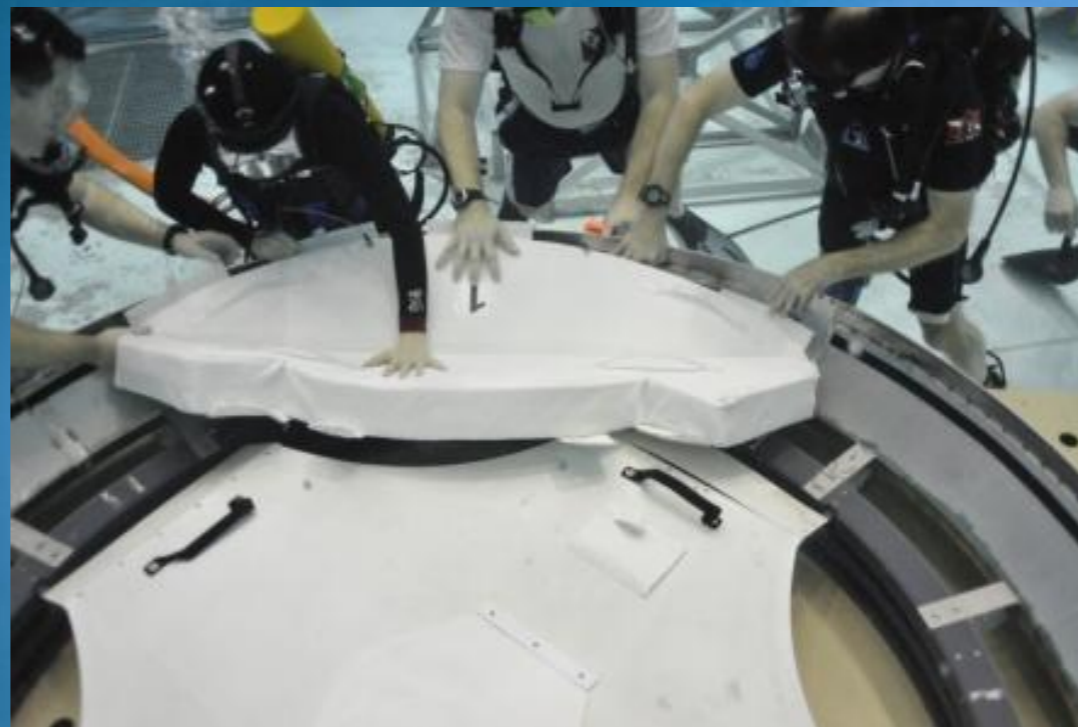
Daily Operations

NBL Successes & Challenges

Other (non-ISS) NBL Testing

NBL External Customers & Future Uses

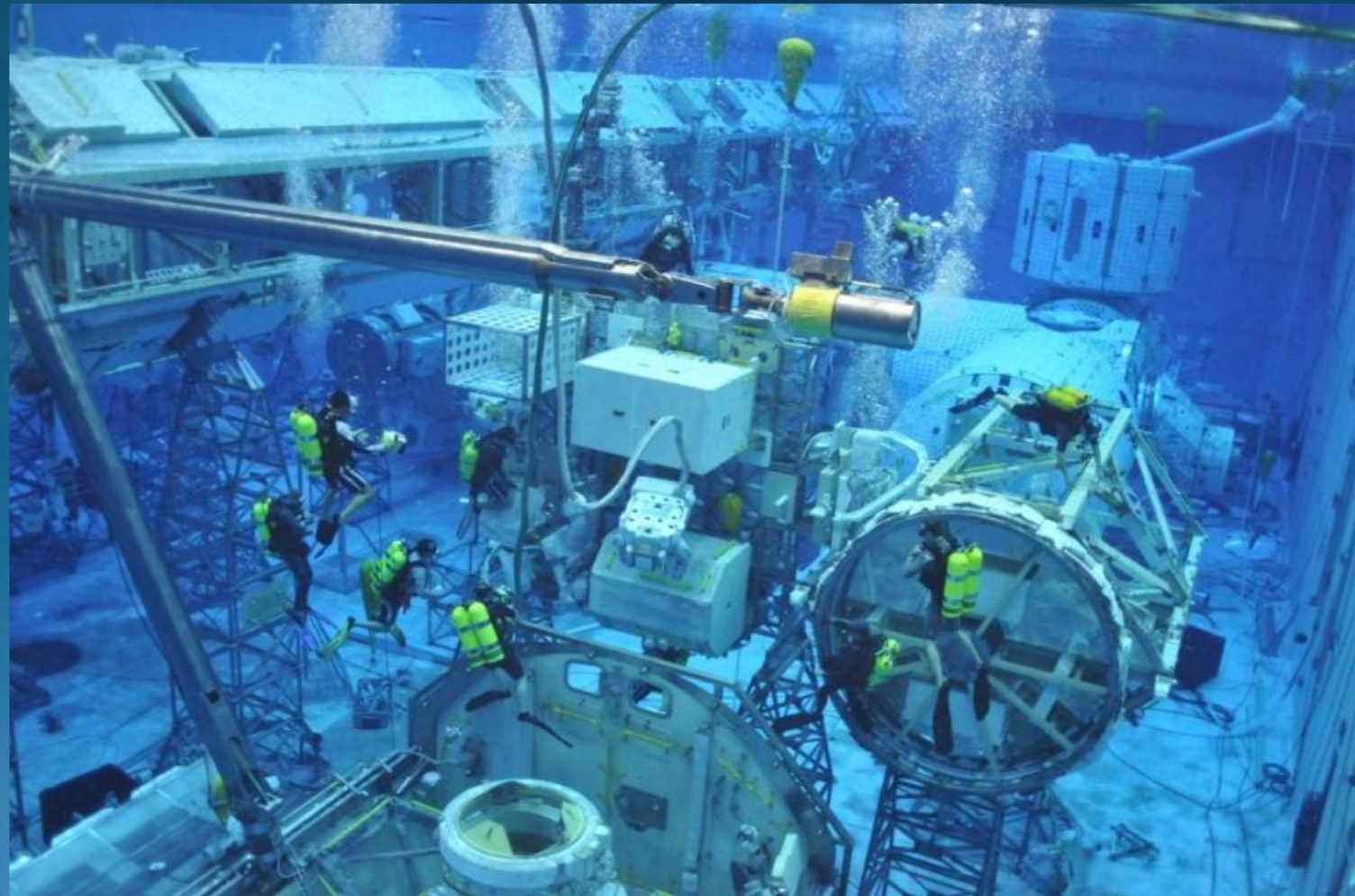
References & Acknowledgements



Background



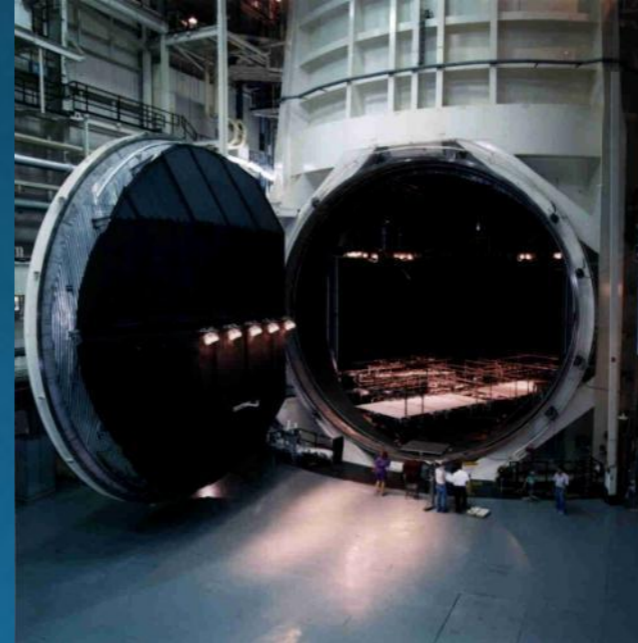
- Large Indoor pool (202' x 102' x 40') for EVA training at JSC
- Built in 1996 to help us assemble the ISS (126 EVAs, 840 sortie hours)
- Accommodates full-scale replicas of the ISS truss complement, US ISS elements, International segments, airlock, pallets, robotic arms, HTV4, shuttle payload bay
- Two simultaneous activities, up to five suited subjects
- 46% oxygen gives suited subjects 400 minutes (~6.7 hrs)
- Essential tool for the design, testing, & development of the ISS & future NASA programs:
 - >1,000 issues identified & resolved through NBL testing
 - >1700 underwater hours



Test Philosophy: Alternatives



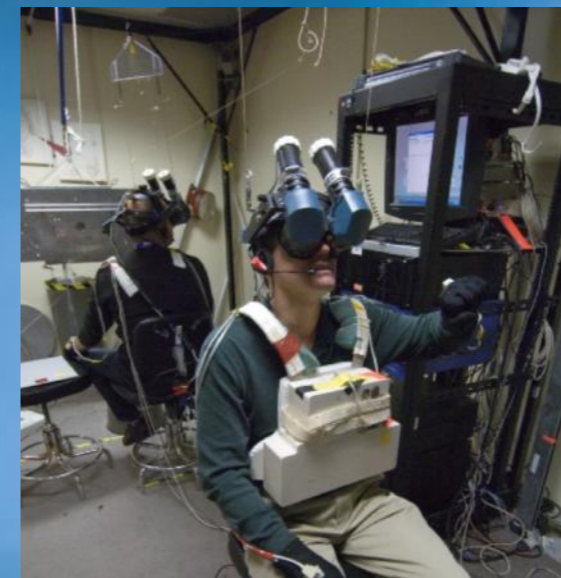
Parabolic Flights:
most realistic
zero/reduced
gravity
simulation (no
drag); however
short, complex,
expensive



**Thermal/Vacuum
Chambers:**
environment
external to
spacecraft, great for
extremely high-
fidelity hardware or
flight hardware
evaluations



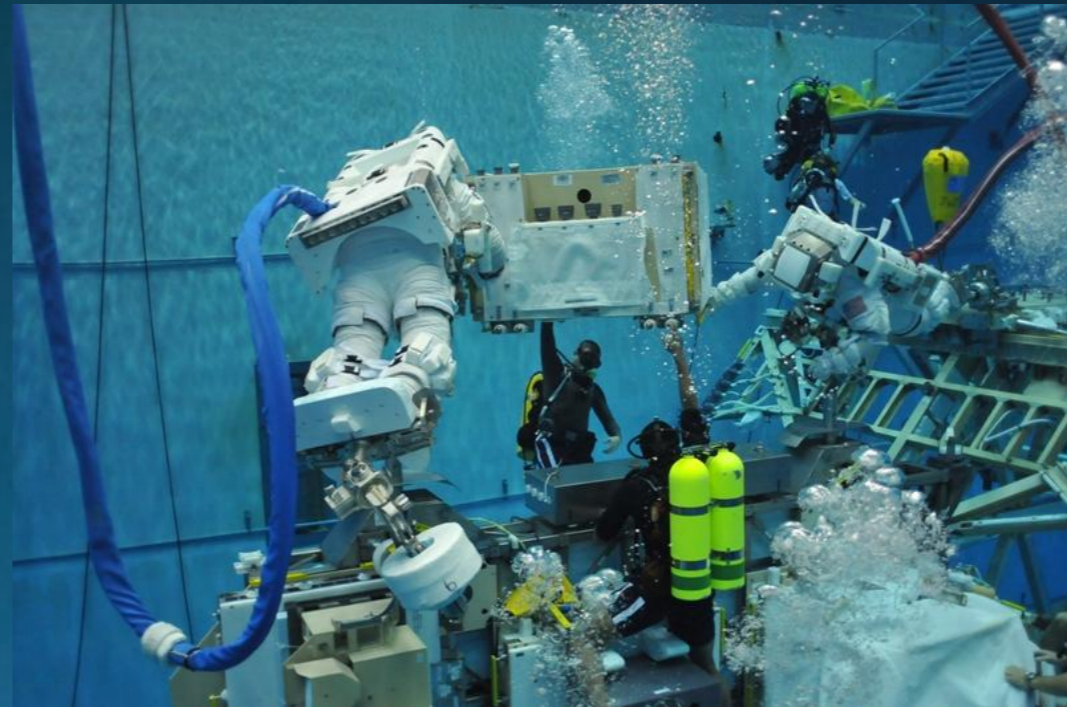
**Gravity Offload
Systems:** data on
reaction forces, body
positioning &
strength
requirements for
tasks; however,
encumbering
attachment devices



**Virtual Reality: 3-D
perspective of
hardware &
interaction between
hardware, crew, &
spacecraft; inertia of
large hardware;
however, site-
specific**

Test Philosophy: Why

- Highly integrated, complex, costly, & risky activities need a robust test facility
- Hardware design evaluation:
 - Translation with equipment
 - Tether point & handrail locations
 - Clearances for glove & tool access
 - Free-float or foot restraint
 - Single or dual crewmember
 - Single or dual-handed
 - Body positioning
 - Torquing
 - Reach
 - Robotic assist

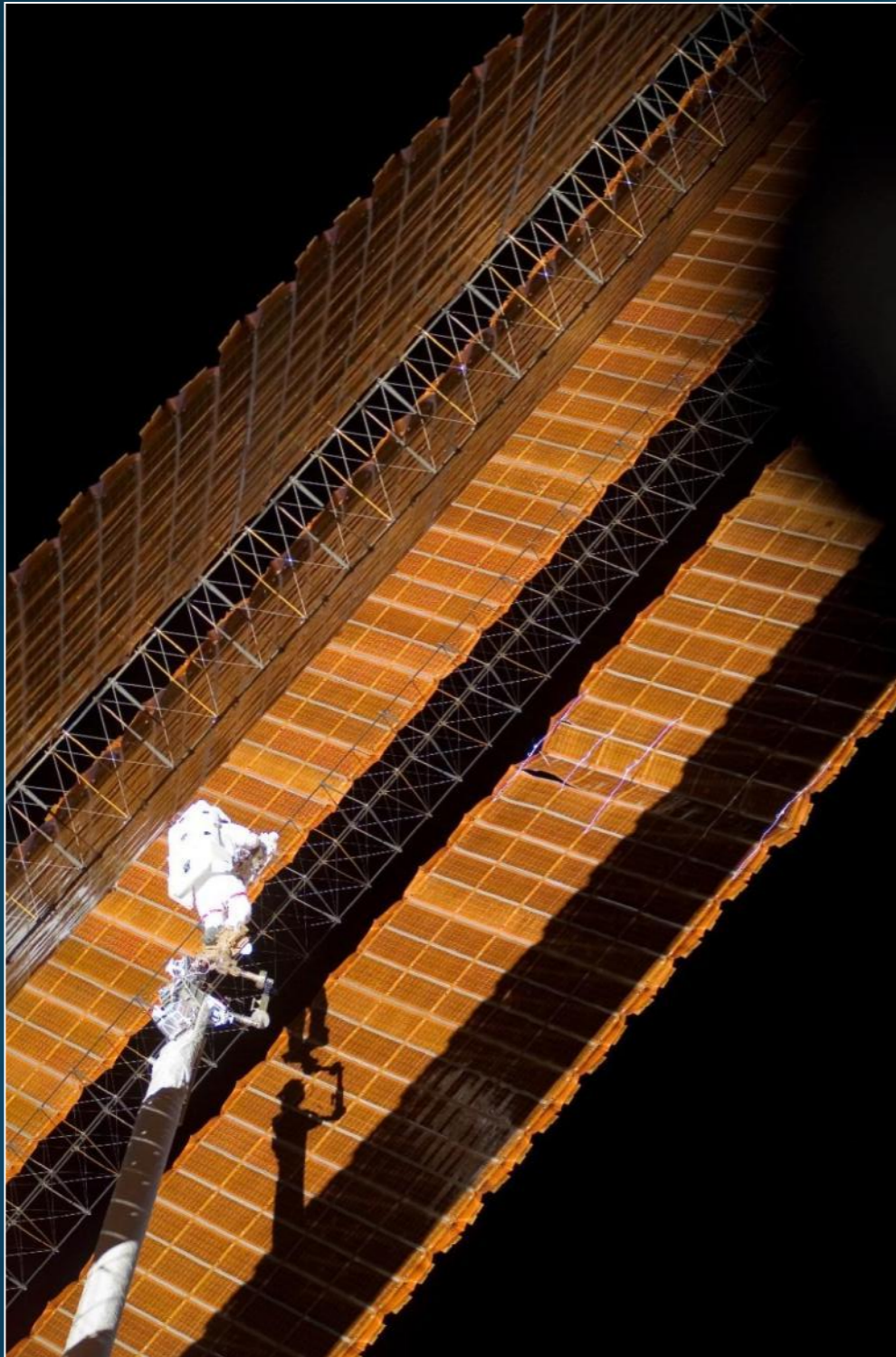


126 EVAs (~840 sortie hours) to build ISS - most complex tasks performed in human spaceflight history

- Hardware certification:
 - Flight hardware requirements closure
 - Rationale to accept hardware in violation of EVA requirements
 - Verification tests
- *What about analysis:*
 - Not ideal for highly complex systems requiring many assumptions
 - More assumptions → less accurate results
 - Insufficient software modeling capabilities



Test Philosophy: Applicable Phases



- **Pre-PDR or Requirements Phase:**
 - Broad hardware concepts & hardware feasibility
 - Low- & medium-fidelity mockups
 - Adequacy of requirements
- **Between PDR & CDR Phase:**
 - Hardware operability in integrated ISS vehicle configuration
 - Medium- to high-fidelity mockups
 - Majority of development & verification testing
- **After CDR Phase:**
 - Validate operations steps & timelines
 - High-fidelity mockups
 - Integrating single tasks into full-length EVAs – minor hardware redesigns

Hardware Development Test Philosophy: Crew Selection



All are EVA-qualified & can make suggestions

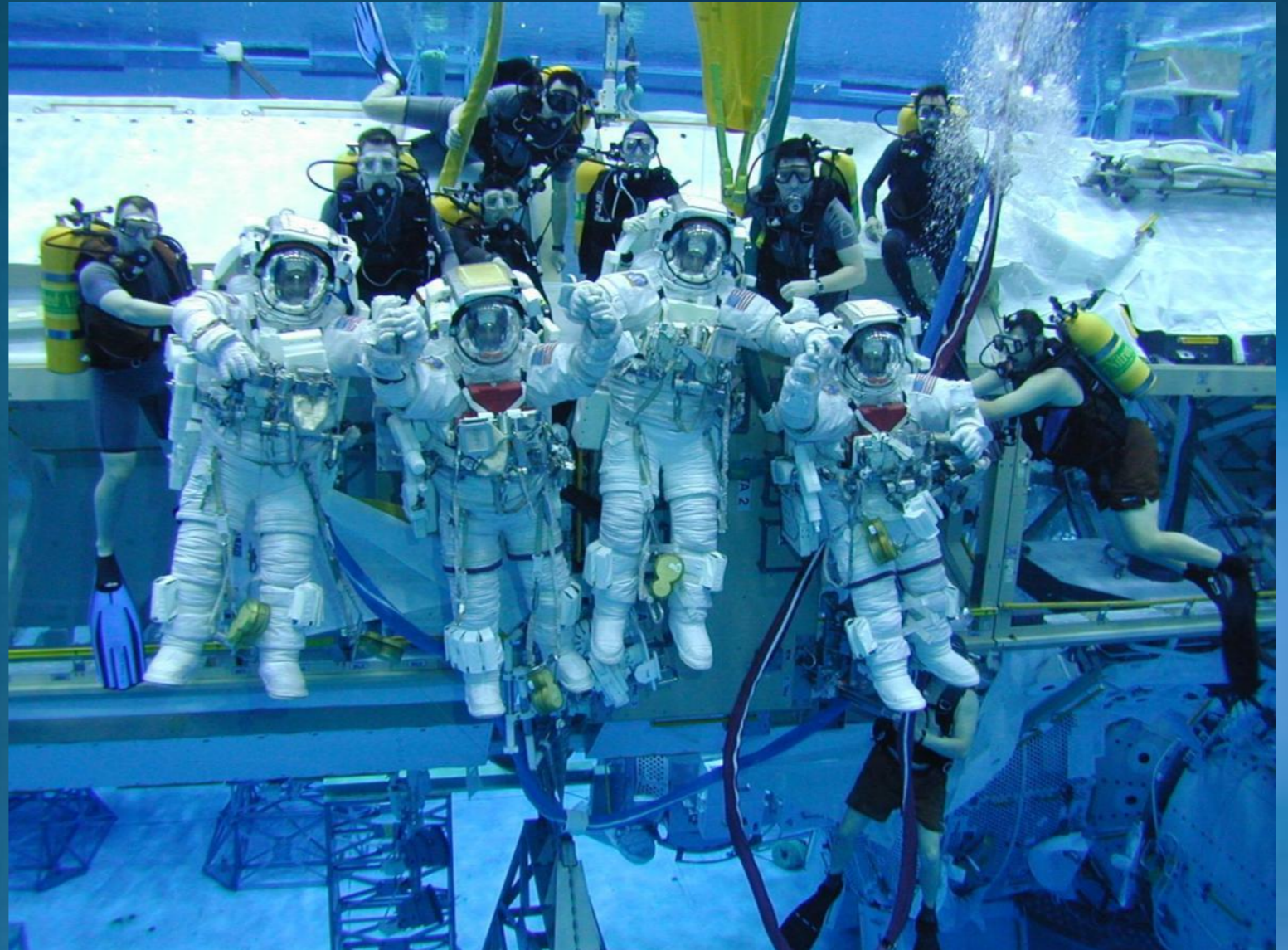
➤ **Anthropometrics:**

- Feasibility - matching worksite to work envelope
 - Breadth of heights
 - Range of arm lengths
 - Various girths

➤ **Skill level & experience mix:**

- Not all perform at the same level
- More skill & experience → more accurate & thorough feedback
- ISS contingency & maintenance – any available crewmember

➤ Six astronauts for official crew consensus

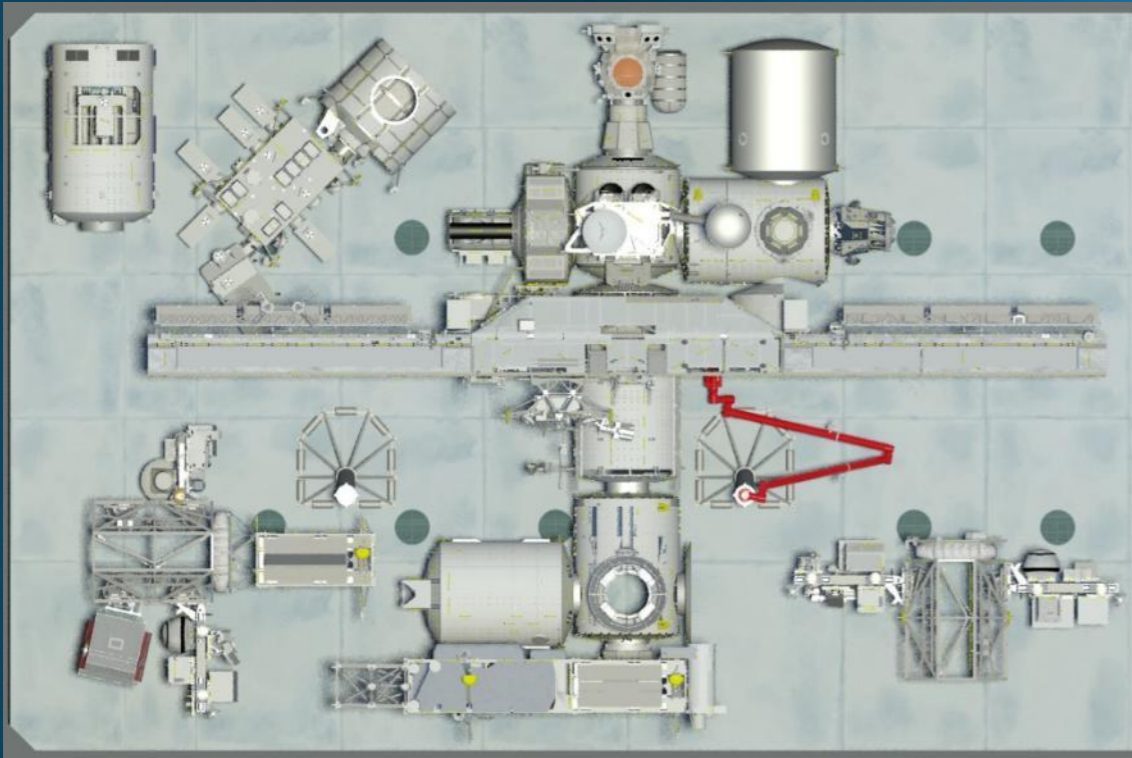


Facility & Test Setup for Hardware Development



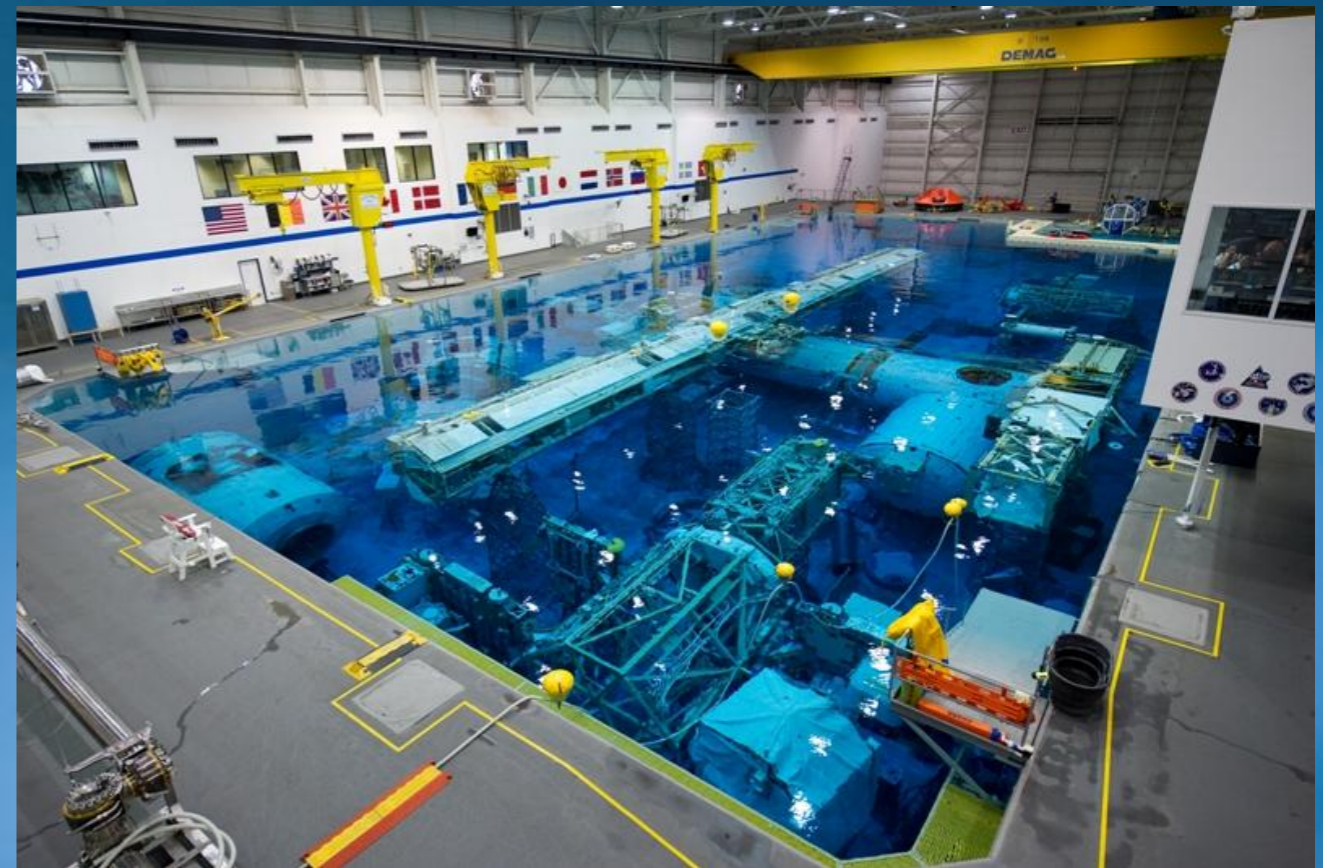
Facility features:

- High bays for staging & maintenance
- 10-ton overhead bridge cranes
- Underwater digital video & audio
- Breathing gas & water cooling through life support umbilicals
- Operations staff:
 - Two safety divers, one utility diver, one camera diver – per subject per test
 - Test director, subsystem operators, suit engineers, suit technicians

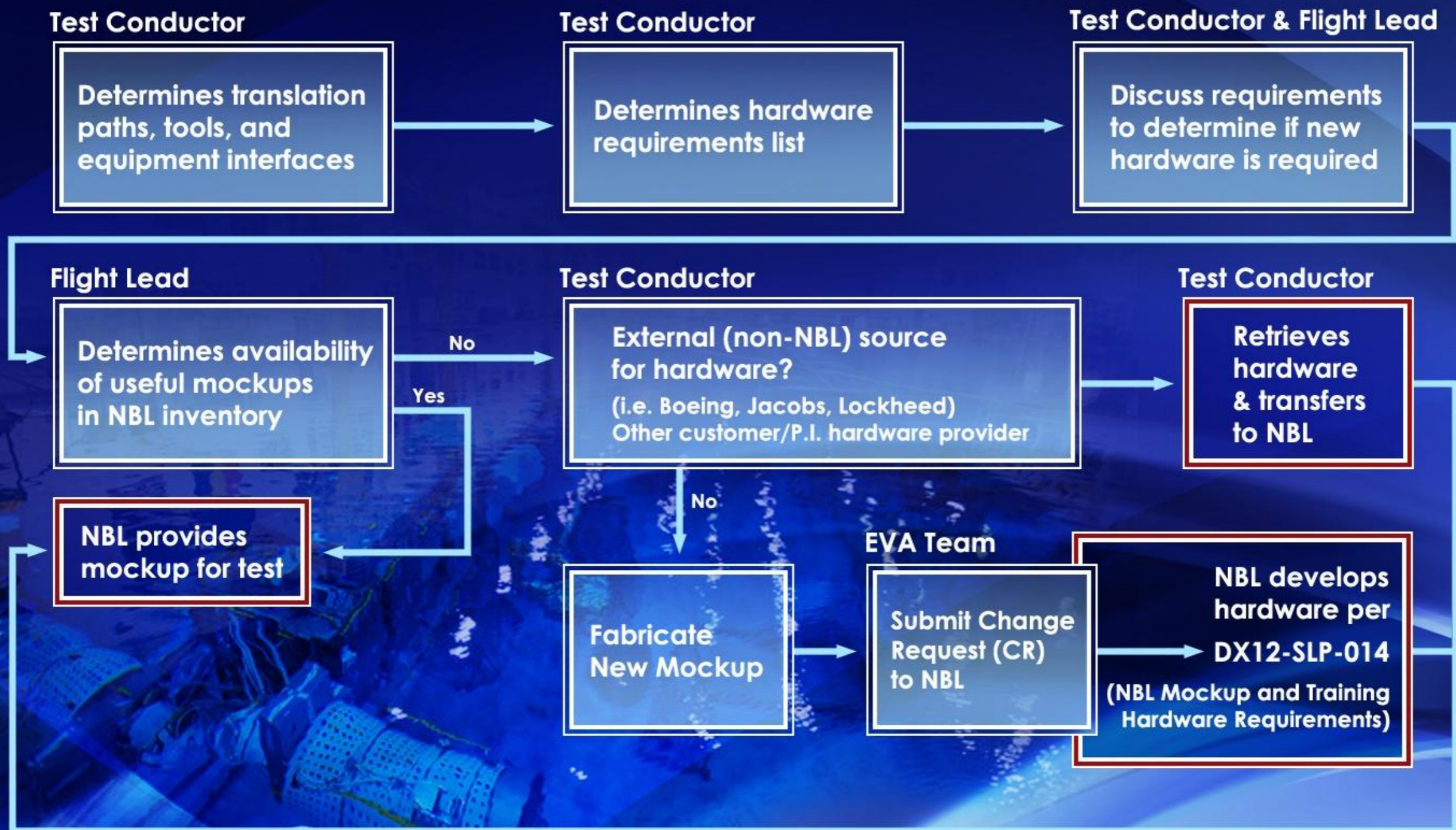


Test events:

- 4-hour scuba run
- 6-hour engineering run
- Three 6-hour suited crew runs, two crew per day



NBL Mockup/Hardware Development Flow



Test Hardware & Mockups

- Fidelity based on training & testing requirements:
 - Flight-like, functionally active, operable, static
 - Class I, Class II, Class III
- Development testing – shorter timelines, unique requirements:
 - Trade-off between cost, fidelity, & schedule
- Special materials proved for long-term use in pool environment:
 - Stainless steel - hi-fi interfaces, bolts, Nodes, etc.
 - Fiber-reinforced plastic – trusses
 - Kydex – skins
 - Ultra-High Molecular Weight (UHMW) polyethylene – small volumetric mockups
- Features to reduce drag, maximize buoyancy:
 - Large lightning holes
 - Embedded foam



Large
Volumetric
Mockup –
Node 2



Small Hi-fi
Mockup –
Node 2 heat
exchangers
with functional
interfaces



Test Planning – Roles & Responsibilities

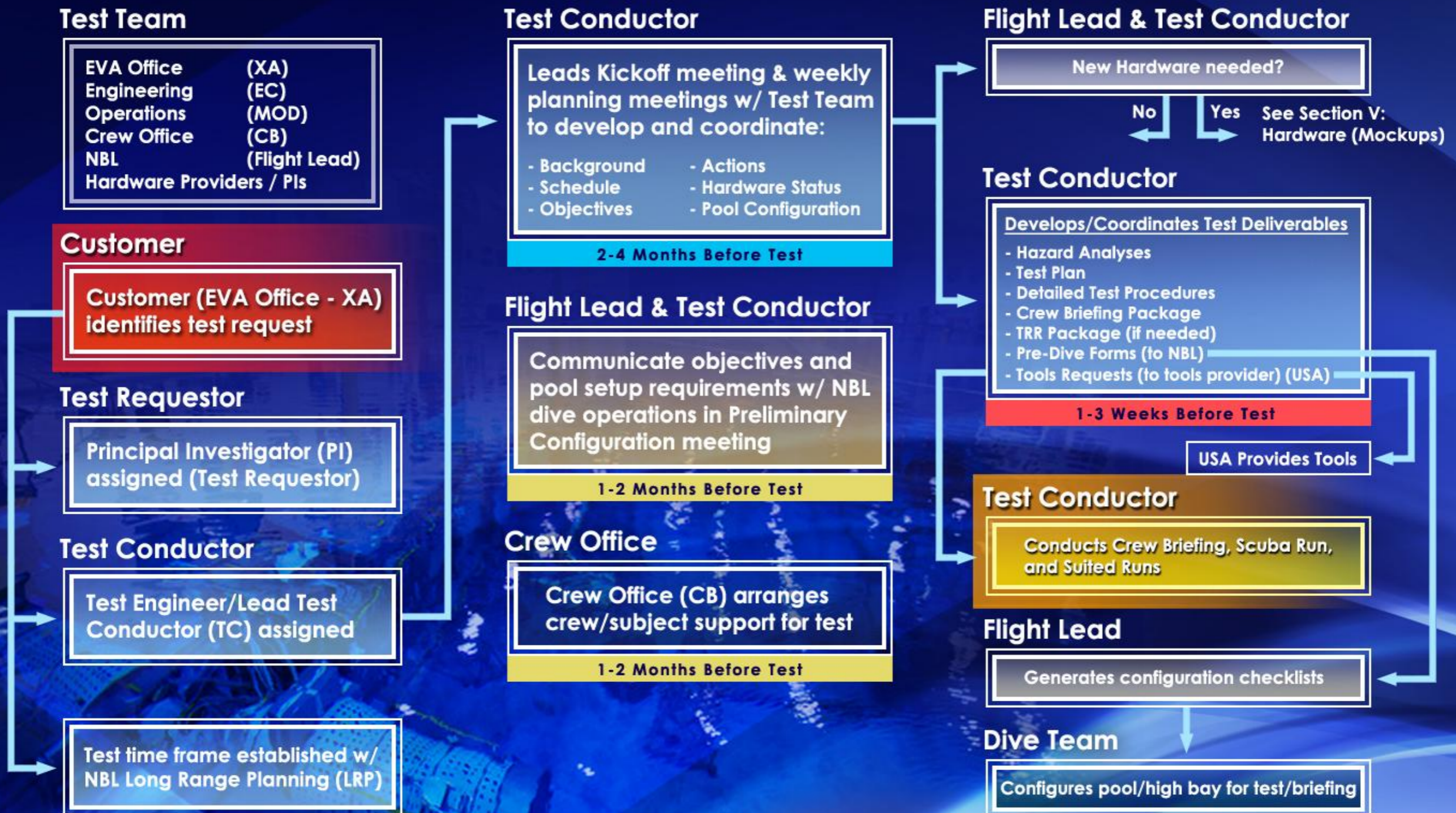
Planning requires multiple roles & typically takes 2 to 4 months



Title	Role	Organization
Principal Investigator	Test requestor	Various
EVA office representative	Determines content to test & prioritizes objectives	NASA/EVA Office (XA)
Test engineer/EDVT lead	Test planning & documentation, lead test conductor	NASA Engineering (EC7)/Jacobs
Mission Operations Directorate (MOD) representative	Provides operations expertise, procedure inputs, & mockup requirements	NASA/EVA Operations (DX32)
Crew Office representative	Selects crew for test, writes crew consensus report	NASA/Astronaut Office (CB)
NBL flight lead	Coordinates pool configuration	NASA/Raytheon (DX12)
NBL project lead	Mockup designer & builder	Raytheon (DX12)



NBL EVA Development & Verification Planning Flow





Daily Operations & Conducting the Test

Daily Operations:

- Morning briefings – subjects, dive team
- Final tool, hardware, & pool setup
- Suit donning, dive, weighout
- Test conducting - 6 hours or objectives complete
- Suit doffing, post-dive debriefing & crew commentary

Working Console:

- Real-time decisions ensure desired objectives are met
- Pre-emptive direction to divers
- Unforeseen test results, pool-use conflicts, delayed starts, suit or mockup issues
- Quick re-planning to drop, reorder, or modify tasks
- Added safety protocols for robotic arm use
- Maximizing facility & personnel time

Data Collection:

- Task accomplishment – success, tools used, foot restraint settings, number of crew, procedure changes
- Video, audio, & still photo
- EDVT Report
- Crew Consensus Report (CCR)



Test Reports



➤ Quick Look Report (3 days)

- Objectives accomplished
- Safety issues or anomalies
- Selection of photos

➤ EDVT Test Report (~4-8 weeks):

- Delta objectives
- Hardware changes
- Final test configuration
- Observations & results (with photos)
- Final detailed test procedures
- CCR

➤ Crew Consensus Report (~4 weeks)

- Official CB position
- Rates test objectives, EVA hardware, & task acceptability – “EVA Hardware & Task Ratings”
- Requirements verification

EVA Hardware & Task Ratings

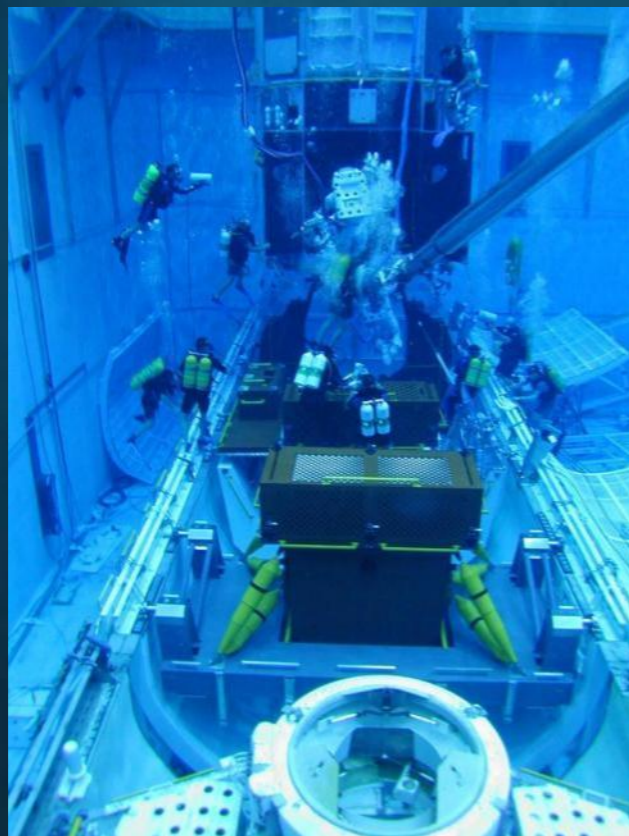


Category	Description
Acceptable (A)	Design changes are not required, although recommendations may be included to improve hardware operations.
Unacceptable 1 (U1)	Design changes are required. Retesting is not required; however, drawing review and/or shirtsleeve inspection of flight or high-fidelity hardware is required to verify adequacy of design changes.
Unacceptable 2 (U2)	Design changes are required. Retesting is required to verify the adequacy of design changes.
Inconclusive (I)	No crew consensus can be reached due to inadequate hardware fidelity, inappropriate test conditions or environment, or an insufficient number of test subjects used. Retesting will be required unless specified otherwise.



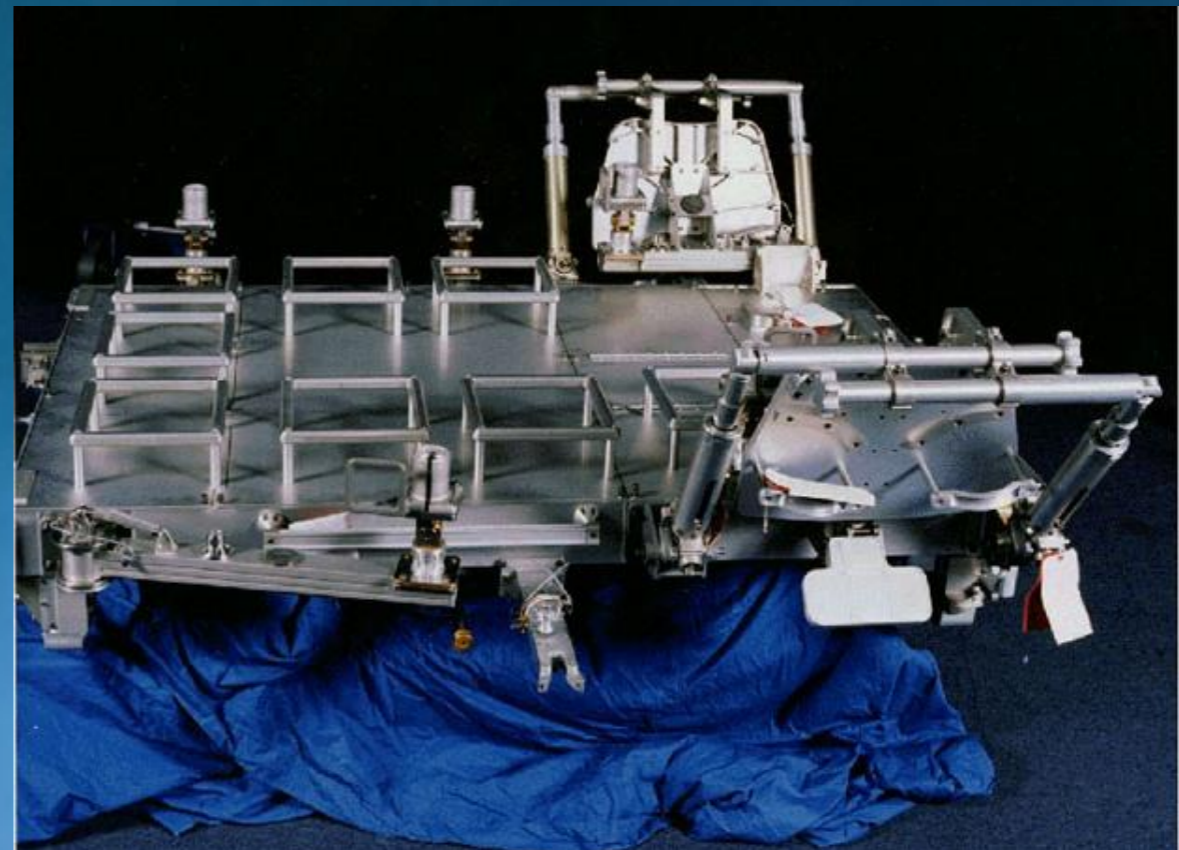
NBL Successes & Challenges

Success – Hubble Servicing



Tasks not originally thought possible in EVA were vetted; specialized new tools were developed & evaluated

Underutilization- CETA Carts

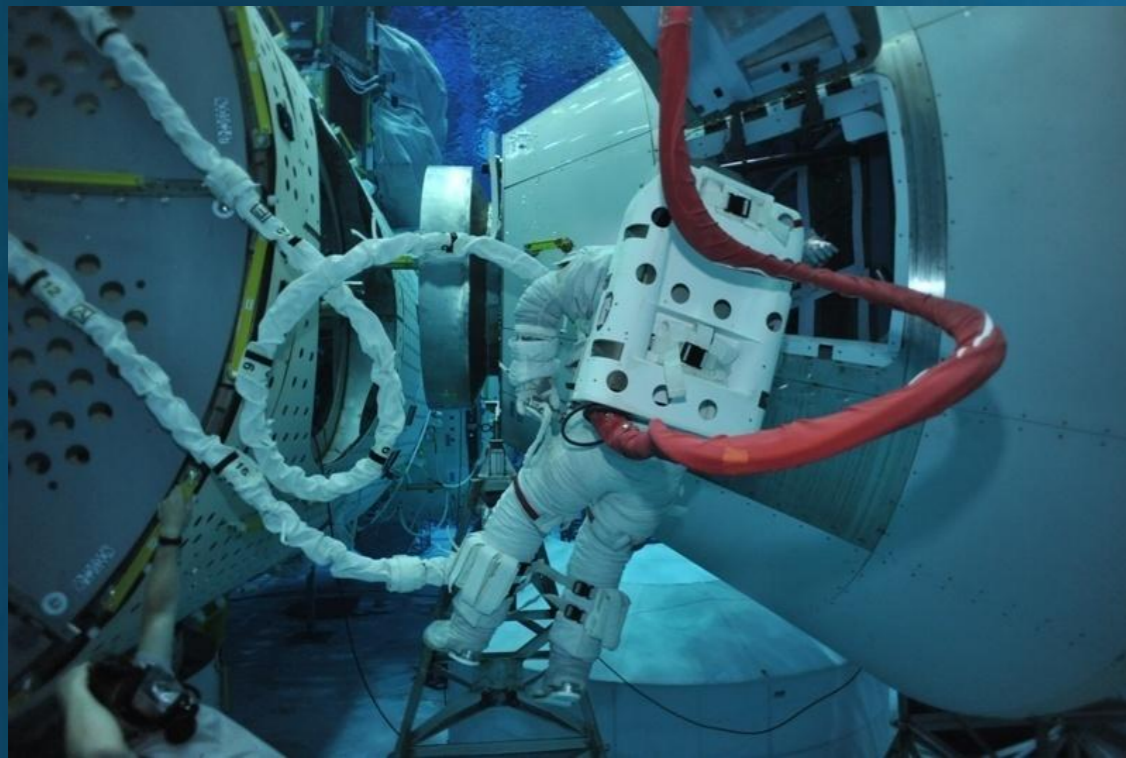


Part-task testing only – evaluation of integrated operations concept would have revealed inefficiencies, potentially cancelled project, saved \$\$

Constellation – Related Testing



- Free-float installation, removal, & stowage of handrails along Altair to Orion translation path
- Hatch opening & closing operations
- Hatch ingress & egress
- All of the above with:
 - Umbilical to Orion
 - Umbilical to Altair (or other vehicle docked with Orion)

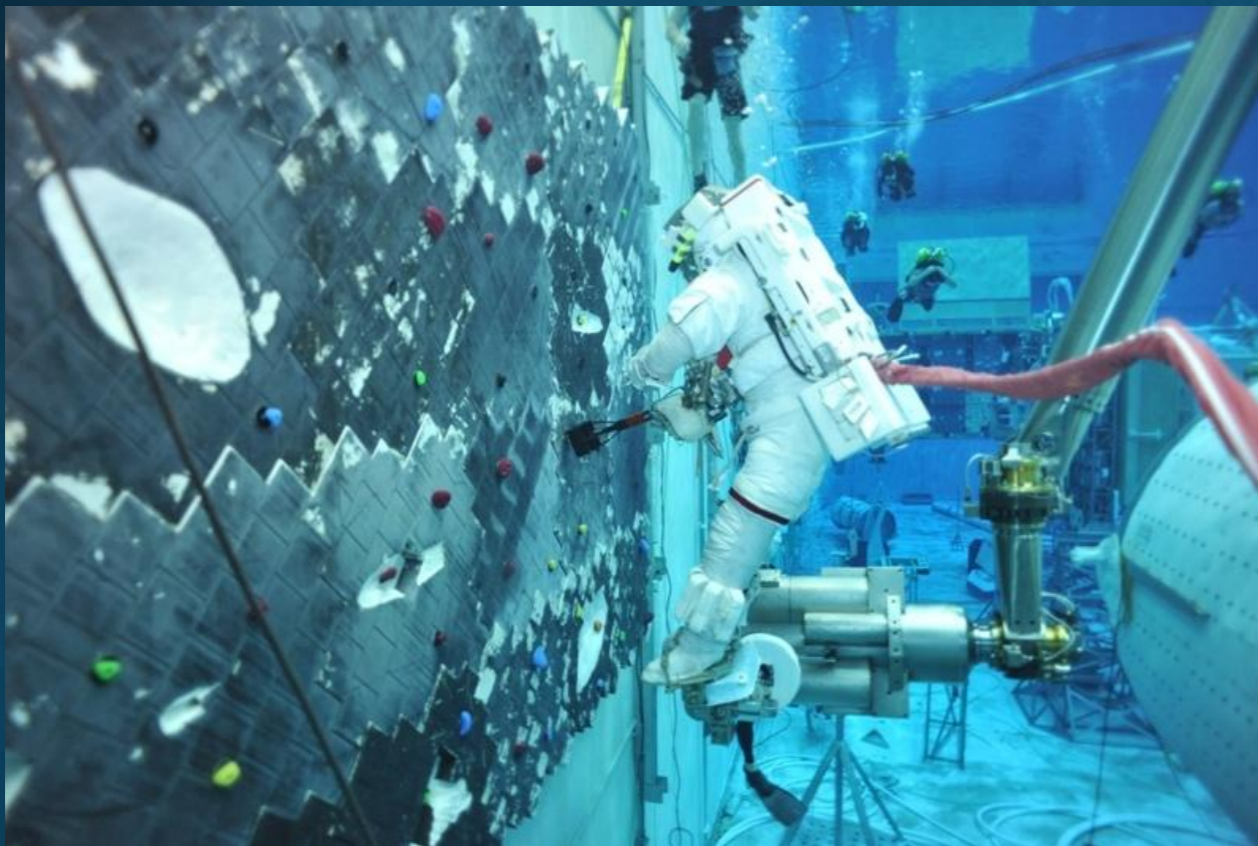


Near-Earth Asteroid Exploration-Related Testing



Rock sampling in micro-gravity environments:

- Robotic arm to represent station-keeping vehicle
- Shuttle tile repair wall to represent asteroid



- Varying asteroid spin speeds
- Various sampling methods:
 - Off-the-shelf tools
 - ISS EVA wipes
 - Empty gloved hand





Future Uses & External Customers

- For external customers, NBL & test teams must be adaptable to the following:
 - Unique operational needs
 - New paradigms
 - Prototypical hardware with more organic, bare-bones approaches to development
 - Shorter, more intense timelines
 - Methodologies & perspectives vastly differing from NASA & government
- NBL commercialization Use Readiness Review (URR) Sept. 2011:
 - Commercial activities to comply with all applicable federal, state, & local requirements; & national consensus standards
 - Use NBL consistent with their normal governing practices rather than unique NASA requirements
- Current & previous external uses:
 - Energy industry – develops & troubleshoots procedure before deep-water use
 - Sensors & advanced imaging, scanning devices, academic research related to human testing
- Potential external uses: Autonomous Underwater Vehicles, ROVs, Atmospheric Diving Systems, intermediate step toward sea trials, EVA for visiting vehicles, new space stations





Conclusions

- Extraordinary facility to establish the human interface in a reduced-gravity environment
- For Shuttle, Hubble, & ISS Programs, NBL was used to evaluate EVA hardware through all phases of the life cycle
- No other facility has all the capabilities necessary to make system integration testing & timeline development for new technologies efficient & productive:
 - Shuttle TPS – not designed for EVA servicing:
 - Post-Columbia testing of innovative operations concepts possible through NBL
 - Re-use of tile board for NEA evaluations
 - Hubble – cost of EVA testing in NBL was fraction of on-orbit EVA cost:
 - Millions of on-orbit dollars have been saved by vetting EVA operations in the NBL first
 - CETA carts - Inadequate up-front testing wasted money, time, project resources
- Testing results in life-cycle cost savings by ensuring hardware meets operational requirements
- *Imperative that future spacecraft designers realize the importance of the NBL even in early phase of hardware design*



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